

INVESTIGATION OF SONIC BOOM FOR THE SPACE

SHUTTLE: LOW CROSS-RANGE ORBITER

By

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INTRODUCTION

It is desired that the space-shuttle orbiter be capable of landing at airports equipped to handle present-day jet transports. Since the majority of such airports are located near heavily populated areas, an investigation has been undertaken to determine whether or not the sonic boom generated during reentry of space-shuttle orbiters is potentially a serious problem. The investigation was concerned with the low cross-range orbiter and reentry concept proposed by Faget (ref. 1) of the Manned Spacecraft Center (MSC). This report describes the approach used and presents the results obtained to date.

NOMENCLATURE*

h	flight altitude
L/D	lift-drag ratio
l	length of body
M	Mach number
p	wind-tunnel free-stream static pressure
r	distance below model in wind tunnel
S	total wing area
s	ray-path along which pressure signal propagates
W	orbiter weight

*All units given in mks and English systems unless otherwise noted.

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α	angle of attack
γ	flight-path angle, negative below the horizontal
Δp	sonic-boom overpressure
μ	Mach angle, $\sin^{-1} 1/M$

Subscripts

e	effective
m	model
p	payload
1, 2	relative values of r

APPROACH

Sonic-boom overpressures are normally estimated using Whitham's theory (ref. 2). His theory is based on the linearized-flow small perturbation potential equation and therefore is limited in its application to slender vehicles at small angles of attack, α . The near-field pressure signature is estimated using the vehicle "F-function" which, for slender vehicles at small α , may be obtained analytically as indicated in reference 2 or semiempirically as demonstrated in reference 3. The near-field signature is then extrapolated to far-field conditions for straight and level flight at constant velocity in a uniform atmosphere. The ground-level overpressures so estimated are subsequently corrected for propagation of the pressure signals through the actual (nonuniform) atmosphere.

In the case of the space shuttle, the orbiter reenters the atmosphere on a predetermined trajectory while flying at a high angle of attack ($\alpha = 60^\circ$). The orbiter flow field is characteristic of a blunt-like vehicle with a strong detached bow wave; see, for example, figure 1. This type of flow field cannot be calculated with linearized-flow theory and the analytical treatment of Whitham is not valid, particularly the analytical determination of the vehicle F-function. Therefore, an alternate approach was taken in the hope that the semiempirical technique

developed by Hicks and Mendoza (ref. 3) for evaluating the F-function for slender vehicles at small α might also be valid for blunt-like vehicles at large α . If so, the semiempirically deduced F-functions could be used to extrapolate experimentally determined near-field pressure signatures of the shuttle orbiter to flight conditions. In addition to corrections for a nonuniform atmosphere, corrections for variations in deceleration and flight-path angle along the trajectory could be included.

To investigate the validity of applying the Hicks-Mendoza technique to the MSC low cross-range orbiter, the Whitham near-field theory was used (as described in ref. 3) to deduce an F-function from an experimental pressure signature measured at one distance, r_1 , below a model in a wind tunnel. The deduced F-function was used to predict the signature at a greater distance, r_2 , from the model. Comparisons between the predicted and subsequently measured signature at r_2 showed very good agreement. A typical result is shown in figure 2 for tests at a Mach number, M , of 2.7 and $\alpha = 60^\circ$.

At $r_2 = 1.216$ m (47.88 in.) only half of the signature could be measured due to the limited travel of the survey mechanism. However, the agreement shown between predicted and measured signatures demonstrates that the semiempirical technique of reference 3 is valid for blunt vehicles at large α and provides some measure of confidence that extrapolations of the wind-tunnel data to flight conditions will be valid.

In making the extrapolations to flight conditions, the F-functions deduced from the measured pressure signatures were used in conjunction with Mach-number, altitude, deceleration, and flight-path-angle parameters of a representative reentry trajectory as input to the computer program developed in reference 4. This program calculates the ground-level overpressure directly beneath a vehicle and includes corrections for the effects of decelerating flight through a 1962 standard atmosphere. The atmospheric corrections were further updated using the correction factors more recently published in reference 5.

The corrections for the effects of flight-path angle, γ , were incorporated by using the computer program (ref. 4) to extrapolate the input data to an effective flight altitude. The effective altitude, h_e , was determined for propagation of a signal through a uniform atmosphere and was based on the geometric relationship of the actual flight altitude, h , γ , and the Mach angle μ ($\sin^{-1} 1/M$) shown in figure 3. A pressure signal emitted from the nose of a body, described

relative to the ground by h and γ , propagates normal to μ along ray path s . The strength of the signal reaching the ground is considered to be that directly below the body (normal to the flight path) at altitude h_e . Thus,

$$h_e = h \frac{\cos \mu}{\cos(\gamma + \mu)}$$

RESULTS

Experimental pressure signatures were measured in the Ames Unitary-Plan Wind Tunnels for a 0.178-meter (7 in.) model (body length) of the MSC low cross-range orbiter at $\alpha = 60^\circ$ and Mach numbers of 1.2, 1.68, 2.17, and 2.7. One signature was also measured at $\alpha = 16^\circ$ and $M = 1.2$. The flight conditions considered correspond to the altitude-, deceleration-, flight-path-angle-Mach number histories shown in figure 4. These parameters describe a portion of a representative reentry of a 1134 kg-payload (25,000 lb.), 45.7 m-long (150 ft.), 81,600 kg (180,000 lb.) orbiter with a total wing area of 180.3 m^2 (1940 ft^2) flying a descent trajectory at $\alpha = 60^\circ$ and a lift-drag ratio of 0.525.

The sonic-boom overpressures estimated by extrapolating the experimental signatures, as described in the APPROACH section, to the above flight conditions are shown in figure 5 as a function of Mach number. "Acceptable" threshold levels of overpressure for supersonic flight over populated areas have not yet been established by the Federal Aviation Agency. However, the goal of sonic-boom researchers in this country is to design transport aircraft which create ground-level overpressures of 48 N/m^2 (1 psf.) or less. Hence, the estimated Δp for the MSC orbiter of 98 N/m^2 (approx. 2 psf.) at $M = 1.2$ is potentially an objectionable level. This is particularly true when one notes that the present data do not include the effects of rate-of-change of flight-path angle. Haefeli has shown (ref. 6) that corrections for the type of γ maneuvers shown in figure 4 result in increases in Δp , particularly at transonic Mach numbers.

It is of interest to note one promising means of reducing Δp ; that is, by the combined tailoring of the trajectory, the physical and aerodynamic characteristics of the vehicle, and the attitude of the vehicle during reentry. This was partially demonstrated by assuming the angle of attack of the MSC orbiter varies during reentry in such a manner that it negotiates $M = 1.2$ on the same trajectory shown in figure 4, but at $\alpha = 16^\circ$. The result shown in figure 5 for $\alpha = 16^\circ$ at $M = 1.2$ indicates nearly a 50-percent reduction in Δp .

REFERENCES

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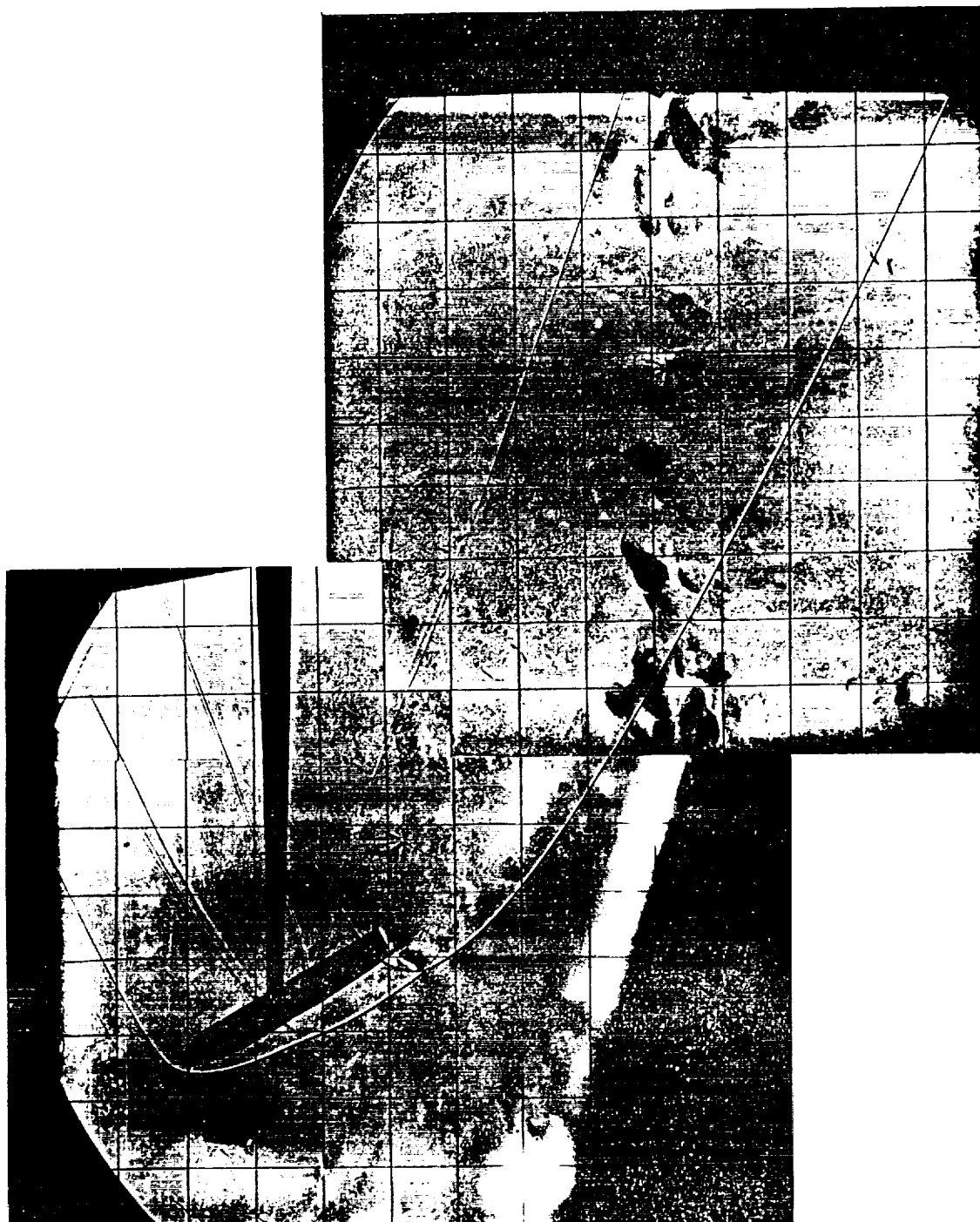


Figure 1.- Shadowgraph of model at $M = 2.7$ and $\alpha = 60^\circ$.

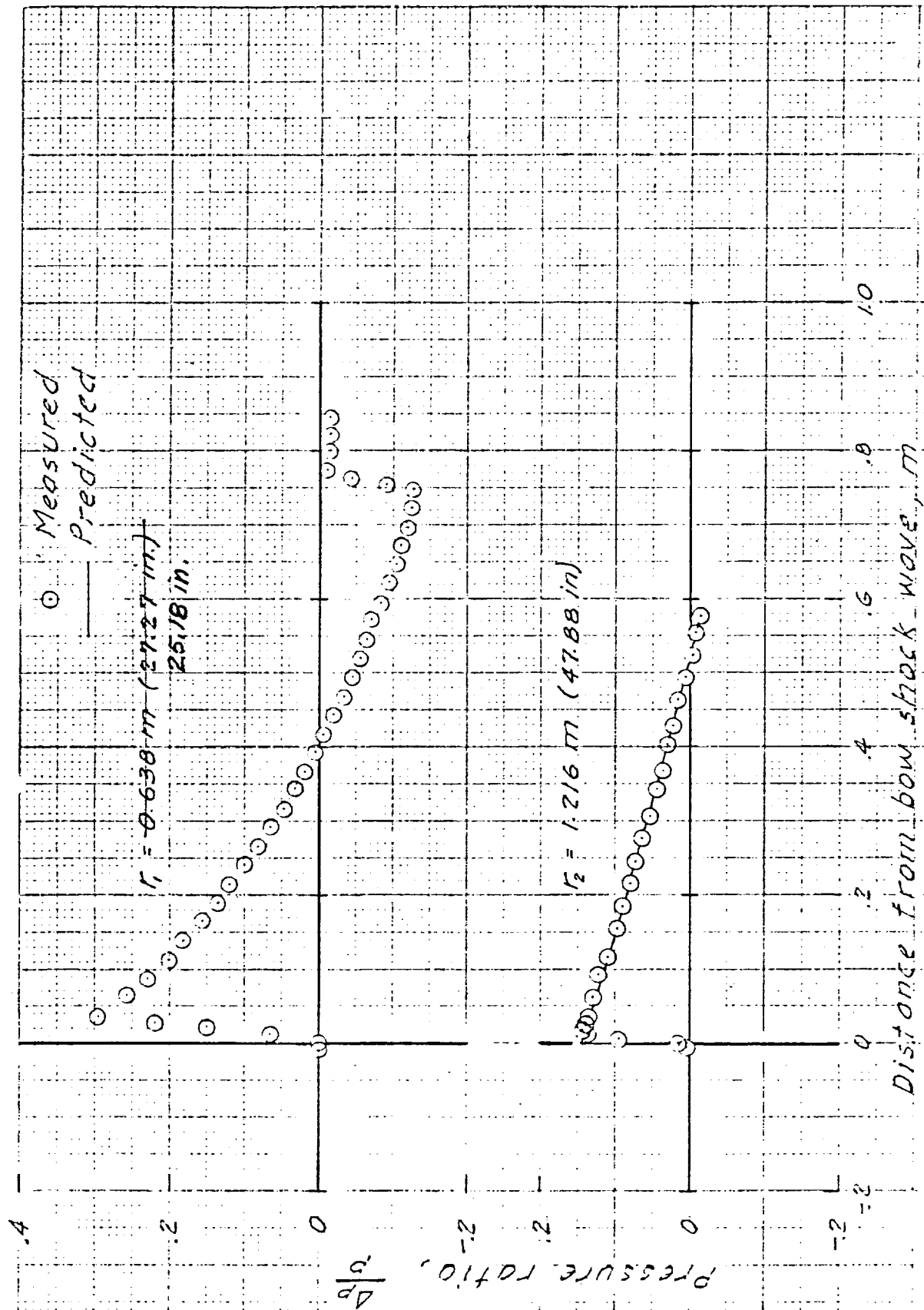


Figure 2. Measured and predicted pressure signatures at $M = 2.7$ and $\alpha = 60^\circ$; $r_m = 0.178 \text{ m (7 in)}$

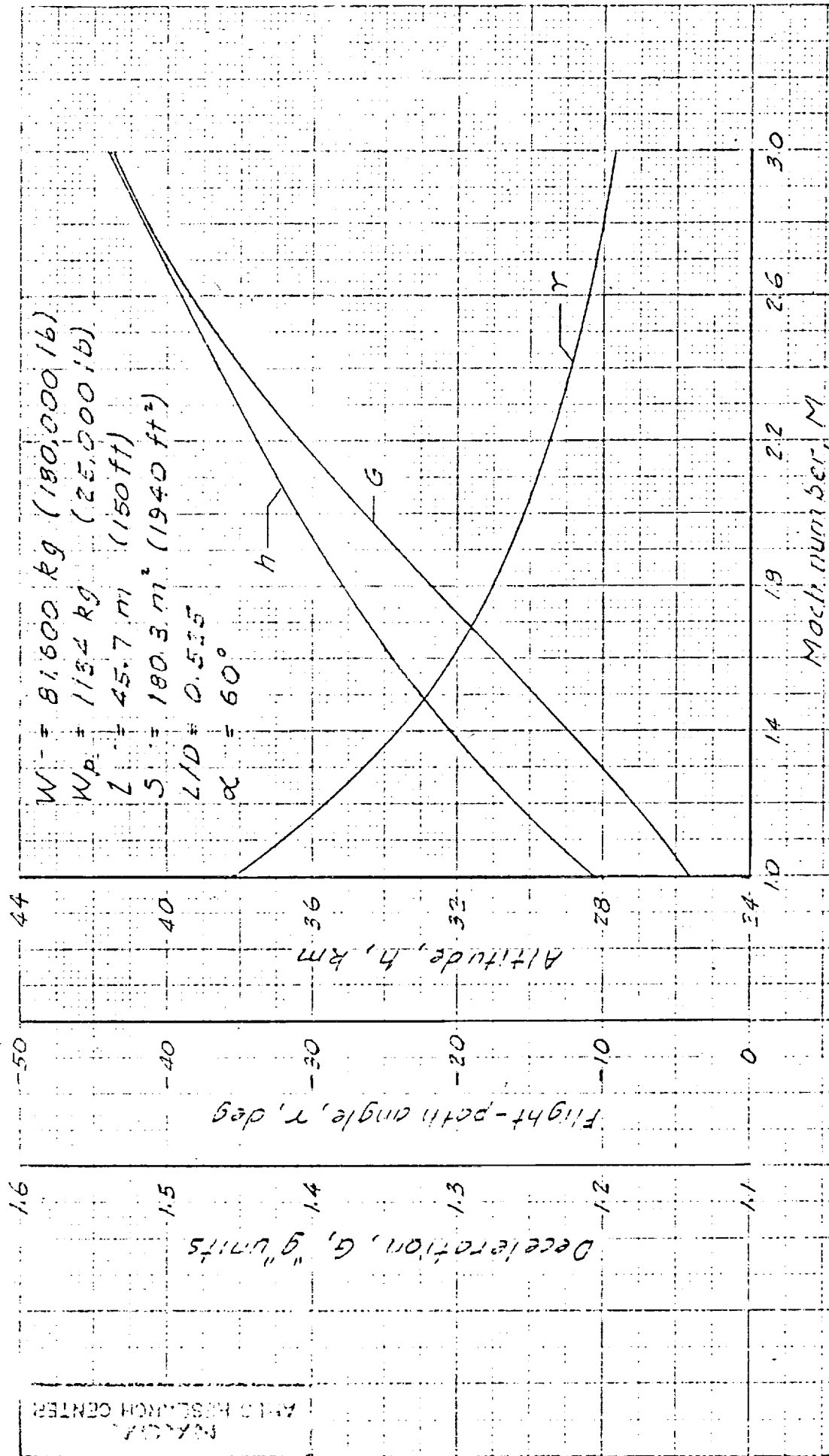


Figure 4. Trajectory parameters for representative reentry.

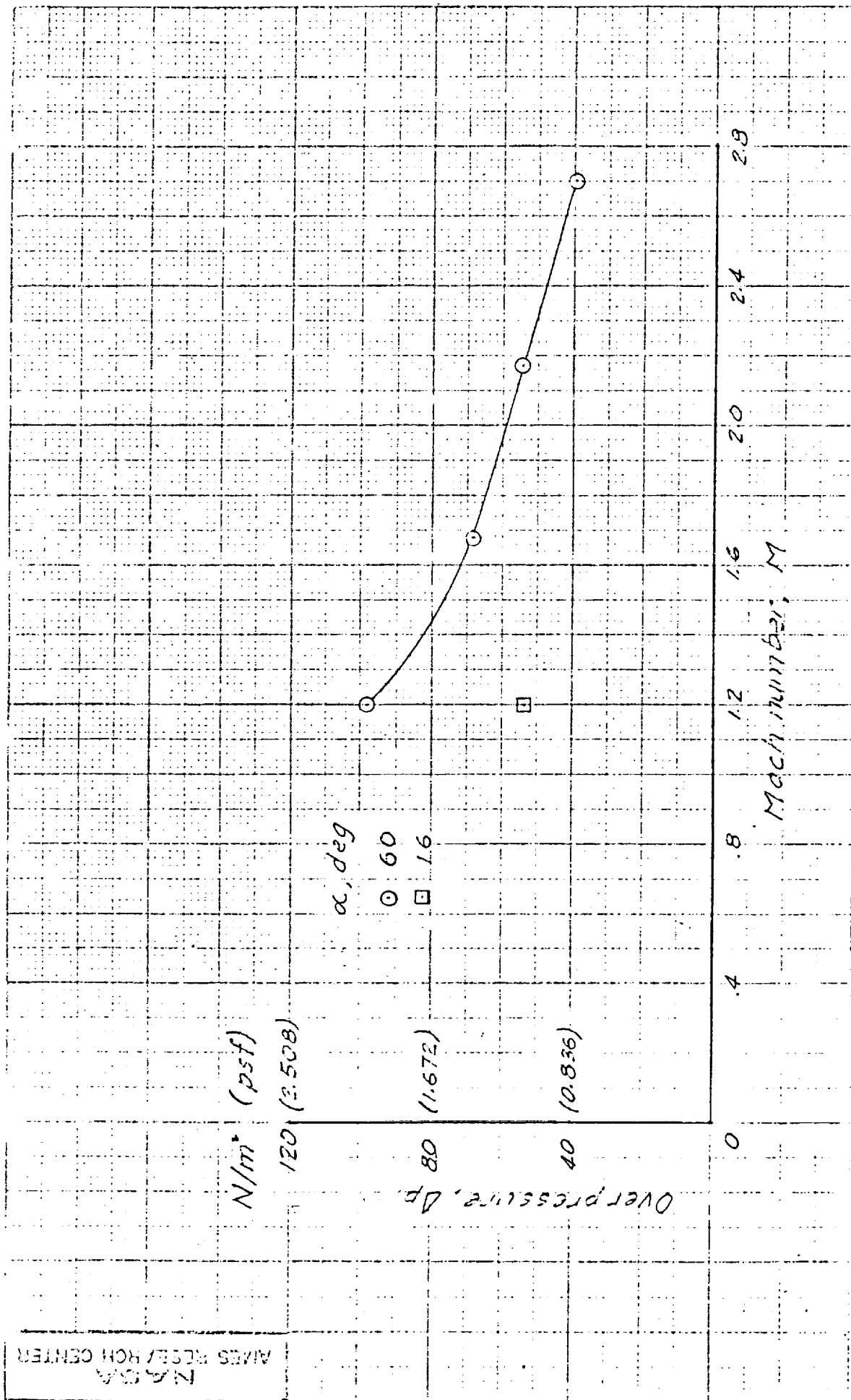


Figure 5. Preliminary estimates of sonic-boom overpressure.